(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 365 216 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
26.11.2003 Bulletin 2003/48

(51) Int Cl.7: **G01F 1/684**, G01F 1/68, G01F 1/692

(21) Application number: 03090136.7

(22) Date of filing: 07.05.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(30) Priority: 10.05.2002 JP 2002135283
23.08.2002 JP 2002243589

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(54) Flow sensor and method of manufacturing the same

(57) A flow sensor includes a substrate, an electrical insulating film, and a flow velocity detection mechanism. In the substrate, a diaphragm portion having a first surface in contact with a measurement target fluid and a thick fixing portion surrounding the diaphragm portion are integrally formed. The electrical insulating film is formed on a second surface of the diaphragm portion which is on a side opposite to the first surface. The flow velocity detection mechanism is arranged on the electrical insulating film. A method of manufacturing a flow sensor is also disclosed.

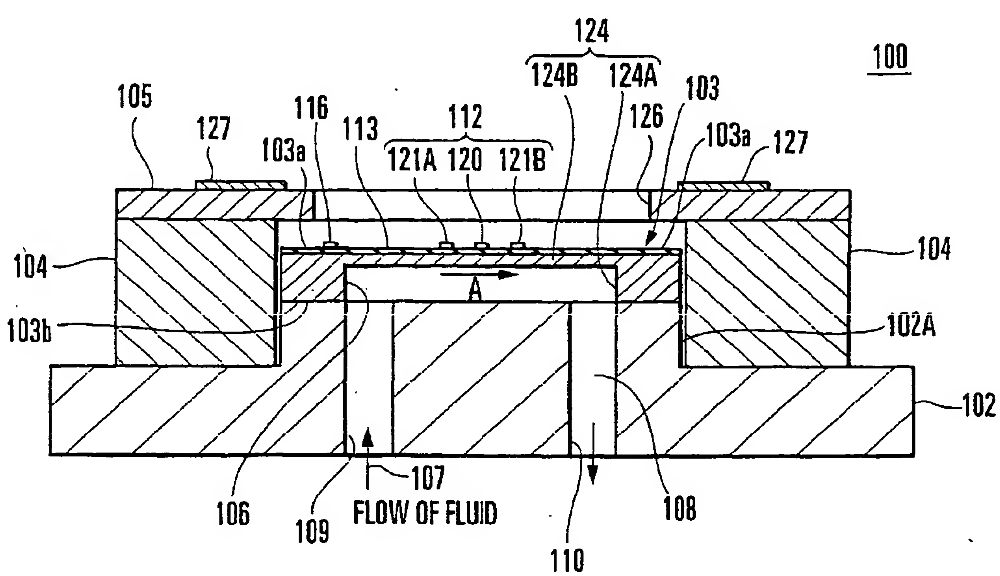

FIG. 1

EP 1 365 216 A1

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Description

Background of the Invention

[0001] The present invention relates to a flow sensor used for measuring the flow velocity or flow rate of a fluid flowing in a channel and, more particularly, a thermal flow sensor.

[0002] In a thermal flow sensor for measuring the flow velocity or flow rate of a fluid, a sensor chip having a flow velocity detection mechanism is arranged in a pipe parallel to the flow of a fluid to be measured. In the flow velocity detection mechanism, the spatial temperature distribution of a fluid is localized by the flow of heat emitted from a heat-generating body (heater). This localization is detected by a temperature sensor (indirect heated type), or a change in power or resistance occurring when the heat of the heat-generating body is deprived of by the fluid is detected (self-heating type), thus measuring the flow velocity or flow rate (examples: Japanese Patent Laid-Open No. 4-295724, No. 2-259527, No. 8-146026, and the like).

[0003] Figs. 17A and 17B show a conventional flow sensor. This flow sensor 1 has a channel forming member 4 for forming a channel 3 for a fluid 2, a substrate 5 having a peripheral portion bonded to a front opening 4a of the channel forming member 4, and a plate 6 fixed (contact-bonded) to the front surface of the substrate 5 by urging it with bolts or the like through an electrical insulating film 13. In this flow sensor 1, the central portion of the substrate 5 forms a diaphragm portion 5A, and a heat-generating body and two resistors (temperature sensors) for constituting a flow rate detection sensor, and their circuit pattern 7 are formed by known thin film forming technique.

[0004] In the flow sensor 1, the substrate 5 is formed thin, and the rear surface of the substrate 5 is in contact with the fluid 2 to form part of the channel 3 together with the channel forming member 4. As the material of the channel forming member 4 and substrate 5, a material having low thermal conductivity, high heat resistance, and high corrosion resistance, e.g., SUS304- or SUS316-based stainless steel is used.

[0005] The plate 6 has a through hole 8 having substantially the same size as that of the diaphragm portion 5A at its center. An electrode 9 is built into the through hole 8. As the electrode 9, one obtained by sealing a plurality of terminal pins 11 in a metal frame 10 with hermetic glass 12 is used. One end of each terminal pin 11 is connected to the circuit pattern 7 by brazing or soldering.

[0006] In the conventional flow sensor 1 described above, the plate 6 is merely contact-bonded to the front surface of the thin substrate 5 by fastening with the bolts. Accordingly, the mechanical and thermal contact between the substrate 5 and plate 6 is unreliable and unstable, making the temperature distribution of the diaphragm portion 5A unstable. Upon a pressure change of the fluid 2, when the diaphragm portion 5A of the substrate 5 elastically deforms in the planar direction, the contact state of the substrate 5 and plate 6 changes, and the temperature distribution of the diaphragm portion 5A changes. Then, the flow velocity or flow rate characteristics or the zero point of the sensor shift , and precision, reproducibility, reliability, and durability are lacking or insufficient.

[0007] Particularly, when the interior of the channel is at a negative pressure, the substrate 5 and plate 6 undesirably separate from each other, and the flow velocity or flow rate characteristics of the sensor change largely.

[0008] Also, the number of components increases, e. g., the plate 6 and a contact-bonding mechanism for the substrate 5 and plate 6, leading to a large, complicated shape.

Summary of the Invention

[0009] It is an object of the invention to provide a flow sensor in which a change in flow velocity or flow rate characteristics caused by the pressure change of the fluid is decreased, so that the precision, reproducibility, reliability, and durability are improved, and which can be fabricated with a reduced number of components.

[0010] It is another object to provide a flow sensor in which zero point adjustment (correction) is performed when the interior of the channel is at negative pressure or vacuum state, so that it can cope with practical needs in the field of semiconductor manufacturing apparatuses of performing flow rate measurement in a pressurized state.

[0011] In order to achieve the above objects, according to the invention, there is provided a flow sensor comprising a substrate in which a diaphragm portion having a first surface in contact with a measurement target fluid and a thick fixing portion surrounding the diaphragm portion are integrally formed, an electrical insulating film formed on a second surface of the diaphragm portion which is on a side opposite to the first surface, and flow velocity detecting means arranged on the electrical insulating film.

Brief Description of the Drawings

[0012]

Fig. 1 is a sectional view showing a flow sensor according to a first embodiment of the invention;
Fig. 2 is a front view of a sensor portion;
Fig. 3 is a circuit diagram showing a constant temperature difference circuit for the flow sensor;
Fig. 4 is a circuit diagram showing a sensor output circuit;
Fig. 5 is a sectional view showing a flow sensor according to a second embodiment of the invention;
Fig. 6 is a plan view of a substrate;
Fig. 7 is a sectional view showing another example

of a sensor chip;

Fig. 8A is a sectional view showing a flow sensor according to a third embodiment ;

Fig. 8B is a sectional view taken along the line A - A of Fig. 8A;

Fig. 9 is a sectional view showing a flow sensor according to a fourth embodiment ;

Fig. 10 is a plan view of a sensor chip;

Fig. 11 is a sectional view showing a flow sensor according to a fifth embodiment ;

Figs. 12A to 12G are views showing the steps in a method of manufacturing a flow sensor according to a sixth embodiment of the invention;

Figs. 13A to 13C are views showing some steps in a method of manufacturing a flow sensor according to a seventh embodiment of the invention;

Figs. 14A to 14C are views showing some steps in a method of manufacturing a flow sensor according to an eighth embodiment ;

Figs. 15A to 15C are views showing some steps in a method of manufacturing a flow sensor according to a ninth embodiment of the invention;

Figs. 16A to 16D are views showing some steps manufacturing a flow sensor according to a 10th embodiment ;

Fig. 17A is a front view showing a conventional flow sensor; and

Fig. 17B is a sectional view showing the conventional flow sensor.

Description of the Preferred Embodiments

[0013] The invention will be described in detail by way of embodiments shown in the accompanying drawings.

[0014] In Figs. 1 and 2, a flow sensor 100 is constituted by a sensor body 102, a sensor chip 103 arranged on sensor body (channel forming member) 102, a printed board 105 similarly disposed on channel forming member 102 through a spacer 104 and located above sensor chip 103, and the like. The sensor body 102 forms a channel 108 for a fluid 107 together with sensor chip 103.

[0015] The sensor chip 103 is constituted by a substrate 124, a flow velocity detection mechanism 112 formed at the center of the upper surface of substrate 124 through an electrical insulating film 113, an ambient temperature detection mechanism 116, and the like. The substrate 124 has substantially the same size as that of a projection 102A of channel forming member 102. The substrate 124 is a thin, elongated rectangular plate, and has a recess 106 at the center of its lower surface. The recess 106 forms a fixing portion 124A with a thick peripheral portion. The fixing portion 124A is bonded to the upper surface of channel forming member 102.

[0016] A thin diaphragm portion 124B is formed on that surface of substrate 124 on which recess 106 is formed. More specifically, elliptic recess 106 is formed in the lower surface of the central portion of substrate 124, thus forming thin portion 124B, which has a thickness (plate thickness) of about 50 μm to 150 μm to form a sensor portion having a diaphragm structure. The length (width) of thin portion 124B in a direction (short-side direction) perpendicular to the flowing direction (direction of an arrow A) is preferably about 1 mm to 3 mm from the viewpoint of the flow strength (pressure resistance).

[0017] Although recess 106 is elliptic, the invention is not limited to this, and recess 106 can be circular or rectangular. The thick fixing portion 124A surrounding diaphragm portion 124B is formed on the upper surface of projection 102A by, e.g., YAG laser welding. The diaphragm portion 124B has a thickness of about 50 μm to 150 μm, and has flow velocity detection mechanism 112 at the center of its upper surface. The recess 106 has an elliptic shape which is long in the longitudinal direction of substrate 124, and communicates with channel holes 109 and 110 at its two ends. The flow velocity detection mechanism 112 is formed on that side of substrate 124 which is opposite to recess 106. An upper surface 103a of substrate 124 is mirror-polished, and electrical insulating film 113 is formed on it.

[0018] As the material of substrate 124, a material having lower thermal conductivity than that of silicon and high heat resistance, high corrosion resistance, and high rigidity, e.g., stainless steel, sapphire, or a ceramic material is used. Among these materials, as stainless steel is a conductive material, if it is employed to form substrate 124, the electrical insulating film is formed on it. As sapphire or a ceramic material is an insulating material, if it is employed to form substrate 124, no electrical insulating film need be formed on it. In flow sensor 100 according to the first embodiment, the substrate 124 is formed of a stainless steel (particularly SUS316L) thin plate having a thickness of about 0.3 mm to 3 mm.

[0019] When substrate 124 is made of stainless steel, if the thickness of the diaphragm portion (thin portion) 124B which forms sensor portion is 50 μm or less, the strength decreases, which is not preferable. If the thickness of the diaphragm portion (thin portion) 124B is 150 μm or more, the thermal conductivity in the direction of thickness of substrate 124, i.e., between fluid 107 and flow velocity detection mechanism 112 decreases, and the heat transfer amount (heat loss) in a direction parallel to the surface of substrate 124 increases, which is not preferable. The fixing portion 124A of substrate 124 serves to keep the shape of diaphragm portion 124B and as a heat sink.

[0020] The recess 106 of substrate 124 is fabricated by photolithography and etching or end milling, or a composite technique of them. When photolithography and etching are employed, first, a resist is applied to the entire lower surface of a stainless steel wafer by spin coating or the like, or a resist film is adhered to it. The lower surface of the wafer is then irradiated with ultraviolet radiation (or electron beams) to transfer and expose

a mask pattern onto the resist. Then, the exposed resist is developed with a developing solution to remove the unnecessary portions of the resist. A negative resist or positive resist is chosen in accordance with whether the exposed portion is to be left or removed. The wafer exposes from the resist-removed portion, and the exposing wafer portion is removed by wet etching or dry etching to a thickness of about 50 μm to 150 μm. Subsequently, the remaining resist is separated and removed, and the wafer is cleaned. Consequently, thin portion 124B and recess 106 are formed. In the case of wet etching, the wafer is dipped in an etching solution, or an etching solution is sprayed to the wafer, so the resist is dissolved little by little. In the case of dry etching, the lower surface of the wafer is irradiated with ions or electrons by sputtering or a plasma, so the resist is removed little by little, thus fabricating diaphragm portion 124B and recess 106. When it is made of a ceramic material, the substrate 124 having recess 106 originally may be calcined.

[0021] Of the thin portion 124B, a surface (upper surface) on a side opposite to the side where fluid 107 flows is mirror-polished, and electrical insulating film 113 is formed on its entire surface. The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116, which include a plurality of electrode pads 114, e.g., 6 electrode pads 114 (114a to 114f) and thin metal films 115 for wiring, are formed on the upper surface of electrical insulating film 113 by the known thin film forming technique. For example, flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 are fabricated by depositing a material such as platinum on the upper surface of electrical insulating film 113 and etching it into a predetermined pattern.

[0022] The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 are electrically connected to electrode pads 114 through thin metal films 115 for wiring. The electrode pads 114 are connected to the electrode terminals of printed wiring board 105, provided above substrate 124 through spacer 104, through bonding wires.

[0023] The electrical insulating film 113 is formed of a thin silicon oxide (SiO_2) film, silicon nitride film, alumina film, polyimide film, or the like having a thickness of, e.g., about several thousand Å to several μ. The silicon oxide film is formed by sputtering, CVD, SOG (spin on glass), or the like. The silicon nitride film is formed by sputtering, CVD, or the like.

[0024] The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 will be described in more detail with reference to Fig. 2. The flow velocity detection mechanism 112 is formed of a heat-generating body 120 and two temperature sensors 121A and 121B. The heat-generating body 120 is arranged at substantially the center of thin portion 124B. The two temperature sensors 121A and 121B are arranged upstream and downstream of heat-generating body 120 in the flowing direction of fluid 107.

[0025] The ambient temperature detection mechanism 116 is used to compensate for a change in ambient temperature, i.e., the temperature of fluid 107. The ambient temperature detection mechanism 116 is arranged close to the peripheral portion of diaphragm portion 124B further upstream of the upstream temperature sensor 121A. In other words, ambient temperature detection mechanism 116 is arranged on the upstream side and outside diaphragm portion 124B. Note that the position of ambient temperature detection mechanism 116 is not limited to the upstream side, but can be the downstream side, either side of sensor chip 103 in the widthwise direction, or on diaphragm portion 124B.

[0026] The pattern width of the heat-generating body 120 is preferably about 10 μm to 50 μm, and those of temperature sensors 121A and 121B and ambient temperature detection mechanism 116 are preferably about 5 μm to 20 μm. If ambient temperature detection mechanism 116 is adversely affected by heat from heat-generating body 120, ambient temperature detection mechanism 116 is not arranged on thin portion 124B of substrate 124 but on another portion, e.g., on the thick portion (fixing portion 124A), which is optimal for detection of the ambient temperature. Also, ambient temperature detection mechanism 116 can be substituted by an external temperature sensor.

[0027] The sensor body (channel forming member) 102 is formed of a metal plate of stainless steel which is thin and elongated in the same manner as substrate 124. The sensor body (channel forming member) 102 also has the protrusion (projection) 102A formed at the center of the surface (upper surface) and having a shape substantially the same as that of substrate 124, and the two channel holes 109 and 110 which form channel 108 for measurement target fluid (to be also referred to as fluid hereinafter) 107 together with recess 106 of sensor chip 103. More specifically, sensor body (channel forming member) 102 has the two through holes 109 and 110. The opening at one end of through hole 109 and the opening at one end of through hole 110 are open near the two ends in the longitudinal direction of the projection 102A, and the opening at the other end of through hole 109 and the opening at the other end of through hole 110 are open in the lower surface of channel forming member 102.

[0028] The fixing portion 124A is bonded to the upper surface of protrusion (projection) 102A. The through holes 109 and 110 and the recess 106 of substrate 124 communicate with each other to form channel 108 for fluid 107. The shape of channel 108 need not be elliptic in recess 106, and a shape with which the flowing direction of fluid 107 is clear so fluid 107 flows smoothly is preferable. When such a sensor body (channel forming member) 102 is fabricated from stainless steel which is the same material as that of substrate 124, channel forming member 102 and substrate 124 can be welded by YAG laser welding or the like without using any dif-

ferent type of metal. Alternatively, channel forming member 102 can be made of aluminum, a ceramic material, or the like. In this case, channel forming member 102 and substrate 124 are bonded to each other by using an O-ring, bolts, or the like.

[0029] Even when channel forming member 102 is made of stainless steel, it may be similarly bonded to substrate 124 by using an O-ring, bolts, or the like. The printed board 105 disposed on the channel forming member 102 through spacer 104 has a circular hole at its center, and a plurality of wiring patterns 127 is formed on its upper surface by printing. The electrode pads 114 of sensor chip 103 are electrically connected to wiring patterns 127 through bonding wires (not shown). The spacer 104 is made of stainless steel, aluminum, a synthetic resin, or the like in the same manner as channel forming member 102. The spacer 104 is fixed to channel forming member 102 with screws, an adhesive, or the like.

[0030] Referring to Fig. 3, heat-generating body 120, ambient temperature detection mechanism 116, and three fixed resistors R1, R2, and R3 form a bridge circuit. The bridge circuit and an operational amplifier (OP1) form a constant temperature difference circuit. The operational amplifier OP1 receives a voltage at the middle point of the bridge circuit, resistor R1, and heat-generating body 120 as an inverting input and a voltage at the middle point of resistors R2 and R3 as a non-inverting input. An output from operational amplifier OP1 is connected to one terminal of resistor R1 and one terminal of resistor R2 in common. The resistances of resistors R1, R2, and R3 are set such that the temperature of heat-generating body 120 is constantly higher than that of ambient temperature detection mechanism 116 by a constant temperature.

[0031] Referring to Fig. 4, the two temperature sensors 121A and 121B and two fixed resistors R4 and R5 form a bridge circuit. The bridge circuit and an operational amplifier OP2 form the sensor output circuit.

[0032] In this flow sensor 100, power is supplied to the bridge circuit of the constant temperature difference circuit shown in Fig. 3 to heat heat-generating body 120 to a temperature higher than the ambient temperature by a certain constant temperature. Then, fluid 107 is supplied in the direction of arrows of Fig. 1. Consequently, thin portion 124B is deprived of heat by fluid 107 proportionally to its flow velocity. Hence, heat-generating body 120 is also deprived of heat, and its resistance decreases. Accordingly, the equilibrium state of the bridge circuit is lost. A voltage corresponding to a voltage generated between the inverting input and non-inverting input of operational amplifier OP1 is applied from operational amplifier OP1 to the bridge circuit.

[0033] Therefore, the heat generating amount of heat-generating body 120 increases to compensate for the heat deprived of by fluid 107. As a result, the resistance of heat-generating body 120 increases, and the bridge circuit is restored to the equilibrium state. Therefore, a voltage corresponding to the flow velocity is applied to the bridge circuit which is in the equilibrium state. In the constant temperature difference circuit of Fig. 3, if the sensor is also used by the heater, of the voltages applied to the bridge circuit, the voltage across heat-generating body 120 can be output as a voltage output.

[0034] When the temperature distribution in the vicinity of heat-generating body 120 is changed by the flow of fluid 107, a temperature difference occurs between temperature sensors 121A and 121B located upstream and downstream of heat-generating body 120. This voltage difference or resistance difference is detected by the sensor output circuit shown in Fig. 4. The temperature difference between two temperature sensors 121A and 121B is proportional to the flow velocity of fluid 107. If the relationship between the channel sectional average flow velocity or flow rate and the temperature difference, i.e., the voltage difference or resistance difference detected by the sensor output circuit, is calibrated in advance, the actual channel sectional average flow velocity or flow rate can be measured from the voltage difference or resistance difference. The arrangement of flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 is not limited to that of the embodiment described above, but can be changed in various ways. Temperature detection mechanism 116 is arranged at a position where it can detect the fluid temperature without being adversely affected by heat from heat-generating body 120.

[0035] With flow sensor 100 having the above structure, the peripheral portion of substrate 124 is bonded as thick fixing portion 124A to the upper surface of channel forming member 102. The central portion of substrate 124 forms the thin portion 124B having a diaphragm structure. The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 are formed on that surface of diaphragm portion 124B which does not come into contact with fluid 107. Therefore, unlike in the conventional flow sensor shown Figs. 17A and 17B, the plate 6 need not be contact-bonded to substrate 5.

[0036] With flow sensor 100, even if thin portion 124B elastically deforms upon a pressure change of fluid 107, no peeling occurs in flow sensor 100. Compared to conventional flow sensor 1 shown in Figs. 17A and 17B, the influence of the pressure on the flow velocity or flow rate characteristics of the sensor decreases, so that flow sensor 100 can be maintained in a stable state over a long period of time. In particular, since the shift of the zero point is small, high measurement precision can be obtained, and the reliability and durability of the sensor can be improved.

[0037] As substrate 124 is integrally formed of thick fixing portion 124A and thin portion 124B, even when thin portion 124B elastically deforms upon a pressure change of the fluid, the position of the fixed end of fixing portion 124A does not change.

[0038] A flow sensor according to the second embod-

iment will be described, in which the invention is applied to a so-called header type flow sensor.

[0039] In a header type flow sensor 150, a sensor chip 154 is externally inserted and fitted in a sensor attaching hole 152 formed in the wall of a pipe 151 through which a fluid 102 flows, and is fixed by welding, or with an O-ring, bolts, or the like. A bracket 153 and the sensor chip 154 form a container. A printed board 155 is accommodated in the container.

[0040] The bracket 153 is made of stainless steel into a cylinder with two open ends, and is externally fitted in sensor attaching hole 152. A flange 153A is bonded to the outer surface of pipe 151. The sensor chip 154 is bonded to the inner end face of bracket 153, i.e., to an open end face of bracket 153 on a side opposite to flange 153A.

[0041] The sensor chip 154 has a substrate 156 made of stainless steel or the like in the same manner as in the first embodiment. The substrate 156 is bonded to the inner end face of bracket 153, and hermetically covers sensor attaching hole 152 of pipe 151. First and second recesses 157a and 157b are formed in that surface 156a of substrate 156 which is on the bracket 153 side. A surface 156b of substrate 156 which is on a side opposite to the surface 156a forms a contact surface which is to come into contact with fluid 102 flowing in pipe 151.

[0042] In the flow sensor according to the second embodiment, since substrate 156 is directly attached in sensor attaching hole 152 of pipe 151, no channel forming member is required. Since substrate 156 can be attached easily even to a pipe with a large diameter, a large flow rate can also be measured.

[0043] Those portions of substrate 156 in which recesses 157a and 157b are formed form thin portions 156B1 and 156B2 having diaphragm structures. The remaining portion of substrate 156 forms a fixing portion 156A, which is bonded to the inner end face of bracket 153.

[0044] The first recess 157a is formed at substantially the center of substrate 156, and second recess 157b is formed upstream of first recess 157a. Electrical insulating films 113 are formed on the bottom surfaces of first and second recesses 157a and 157b, and a flow velocity detection mechanism 125 and ambient temperature detection mechanism 134 are formed on them. More specifically, the two recesses 157a and 157b are formed to prevent ambient temperature detection mechanism 134 from being adversely affected by heat generated by heat-generating body 120 (Fig. 1) of flow velocity detection mechanism 125, and flow velocity detection mechanism 125 and ambient temperature detection mechanism 134 are separately arranged in recesses 157a and 157b. The recesses 157a and 157b preferably have circular shapes each with a diameter of about 1 mm to 3 mm from the viewpoint of strength (pressure resistance), but can have any other shape.

[0045] This sensor chip 154 is fabricated in the same manner as in the first embodiment described above. In this case, a projection aligner and direct writing unit are used in photolithography when forming patterns on the upper surfaces of respective thin portions 156B1 and 156B2 located at the bottom portions of recesses 157a and 157b. Alternatively, the patterns of the resistors and conductors are directly formed by using a jet printing system.

[0046] According to a modification of the second embodiment, as shown in Fig. 7, one recess 157 may be formed at the center of substrate 156, and ambient temperature detection mechanism 134 may be formed on fixing portion 156A. With flow sensor 150 having this structure as well, the same effect as in the first embodiment described above can obviously be obtained.

[0047] Figs. 8A and 8B show the flow sensor according to the third embodiment.

[0048] In the third embodiment, a substrate that constitutes a sensor chip 160 is formed of a stainless steel pipe 161, and the center hole of pipe 161 is used as a flow channel 103 for a fluid 102.

[0049] Hence, flow channel forming member 102 of the first embodiment described above is not necessary, and the sensor chip itself also serves as a channel forming member. In other words, the sensor chip of sensor chip 160 and channel forming member are integrally formed from pipe 161 , which is not limited to one having a circular section, but can be one having a noncircular section such as a rectangular or elliptic section.

[0050] The pipe 161 has a recess 164 formed at the central portion in the longitudinal direction of its outer surface. A smaller-thickness portion between recess 164 and the inner surface of pipe 161 forms a thin portion 165. The recess 164 is fabricated by etching, machining using an end mill or press, or a composite technique of them.

[0051] That surface of the thin portion 165 on a side opposite to the surface to come into contact with the fluid 102 is mirror-finished, and is covered with an electrical insulating film 113. A flow velocity detection mechanism 112 and ambient temperature detection mechanism 116, which include a plurality of electrode pads 114 and thin metal films 115 for wiring identical to those shown in Fig. 2, are fabricated at the center of the upper surface of electrical insulating film 113 by the known thin film forming technique. When pipe 161 is made of an insulator such as a ceramic material, electrical insulating film 113 is not necessary. The ambient temperature detection mechanism 116 may be arranged at the position optimal for temperature detection, or may be substituted by an external sensor.

[0052] In sensor chip 160 having the above structure, one pipe 161 serves as the channel forming member and the substrate for the sensor chip. Hence, no bonding portion is present so fluid 102 does not leak, and the number of components can be further reduced, so that a flow sensor having high reliability can be fabricated.

[0053] A change in flow velocity or flow rate characteristics of the sensor chip which occurs upon a pressure

change of the fluid is small. Thus, the measurement precision, reproducibility, reliability, and durability of the sensor can be improved, and fabrication can be done with a reduced number of components.

[0054] A flow sensor according to the fourth embodiment of the present invention will be described.

[0055] Referring to Figs. 9 and 10, a description of portions that are common with those of the flow sensor (Fig. 1) according to the first embodiment will be omitted.

[0056] A sensor body 102 is formed of a metal plate of stainless steel in the same manner as the flow sensor according to the first embodiment. The sensor body 102 has a projection 102A integrally projecting from the center of its upper surface, and two channel holes 109 and 110 which form a channel 108 for a measurement target fluid (to be also referred to as fluid hereinafter) 107 together with a recess 106 of a sensor chip 103. The channel holes 109 and 110 are formed of through holes. The opening at one end of channel hole 109 and the opening at one end of channel hole 110 are open near the two ends the longitudinal direction of projection 102A in, and the opening at the other end of channel hole 109 and the opening at the other end of channel hole 110 are open in the lower surface of sensor body 102.

[0057] The sensor chip 103 forms a rectangular plate having substantially the same size as that of projection 102A . The sensor chip 103 has recess 106 at the center of its lower surface, so that surface of sensor chip 103 in which recess 106 is formed forms a thin diaphragm portion 128B. A thick fixing portion 128A surrounding diaphragm portion 128B is bonded to the upper surface of projection 102A by YAG laser welding or the like.

[0058] The diaphragm portion 128B has a thickness of about 50 μm to 150 μm, and has a flow velocity detection mechanism 112 (to be described later) at the center of its upper surface. The recess 106 is an ellipse elongated in the longitudinal direction of sensor chip 103, and communicates with channel holes 109 and 110 at its two ends. An upper surface 103a of the sensor chip 103 which is opposite to a passage 108 and where flow velocity detection mechanism 112 is provided is mirror-polished.

[0059] As the material of sensor chip 103, a material having lower thermal conductivity than that of silicon and has high heat resistance, high corrosion resistance, and high rigidity, more specifically, stainless steel is used. As a general-purpose stainless steel stock fabricated by ordinary melting and refining has many particles and defects, generates a large amount of gas to be emitted, and lacks cleanness, it is not suitable as a chip material for the flow sensor 100 used in a semiconductor manufacturing apparatus or the like.

[0060] According to the present invention, a stainless steel stock fabricated by remelting, in accordance with special melting, a stainless steel stock fabricated by ordinary melting and refining is used as the chip material.

[0061] A method of manufacturing a stainless steel stock in accordance with special melting includes two types, that is,

① double vacuum melting of vacuum induction melting (VIM) and subsequent vacuum arc remelting (VAR), and

② melting and casting by electroslab remelting (ESR).

[0062] According to VIM, a steel lump melted and cast by an ordinary atmospheric melting furnace is remelted by a VIM furnace, and is poured into a cast mold, thus manufacturing a steel lump. According to VAR, an arc is generated between a consumable electrode and molten steel in the cast mold in a water-cooled cast copper mold set in the vacuum state. The electrode is remelted by the generated heat, and the molten steel is continuously solidified in the cast mold, thus manufacturing a steel lump. According to ESR, a steel lump is manufactured while melting an electrode material in a cold cast mold by the resistance heat of a molten slug. According to such special melting, since steel is melted while isolating it from the atmosphere, a high degassing effect can be obtained, so that any oxide-type inclusion (particles) can be removed. As a result, special melting has a characteristic feature in that it can fabricate a highly clean, high-quality steel stock.

[0063] The steel lump manufactured by special melting forms a stainless steel stock with a predetermined thickness by forging or hot rolling. The obtained stainless steel stock is further cut into a predetermined size, and an upper surface 103a of the cut piece is mirror-polished and recess 106 is formed at the center of its lower surface 103b, thus fabricating stainless steel sensor chip 103 described above.

[0064] If the thickness of diaphragm portion 128B of sensor chip 130 is 50 μm or less, the strength decreases, which is not preferable. If the thickness of diaphragm portion 128B is 150 μm or more, the thermal conductivity in the direction of thickness of the sensor chip 103, i.e., between fluid 107 and flow velocity detection mechanism 112 decreases, and the heat transfer amount (heat loss) in a direction parallel to the surface of sensor chip 103 increases, which is not preferable.

[0065] An electrical insulating film 117 is formed on the entire upper surface 103a of sensor chip 103. The flow velocity detection mechanism 112 and an ambient temperature detection mechanism 116, which include six electrode pads 114 (114a to 114f) and thin metal films 115 for wiring, are formed on the upper surface of electrical insulating film 117 by known thin film forming technique. For example, flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 are fabricated by depositing a material such as platinum on electrical insulating film 117 and etching it into a predetermined pattern. The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 are electrically connected to electrode pads 114 through the thin metal films 115 for wiring.

[0066] The flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 will be described in detail.

[0067] The flow velocity detection mechanism 112 is comprised of one heat-generating body (resistance heater) 120 and two temperature sensors 121A and 121B, to form an indirect heated type flow velocity detection mechanism. The heat-generating body 120 is arranged at substantially the center of diaphragm portion 128B. The two temperature sensors 121A and 121B are arranged upstream and downstream of heat-generating body 120 in the flowing direction of fluid 107.

[0068] The ambient temperature detection mechanism 116 is used to compensate for a change in ambient temperature, i.e., the temperature of fluid 107. The ambient temperature detection mechanism 116 is arranged on the upstream side and outside diaphragm portion 128B. Note that the position of ambient temperature detection mechanism 116 is not limited to the upstream side, but can be the downstream side, either one side in the widthwise direction of sensor chip 103, or on diaphragm portion 128B. The pattern width of heat-generating body 120 is preferably about 10 μm to 50 μm, and those of temperature sensors 121A and 121B and ambient temperature detection mechanism 116 are preferably about 5 μm to 10 μm. Furthermore, diaphragm portion 128B and the thick fixing portion 128A surrounding it may be formed separately, and may be integrated by thermal diffusion bonding or laser welding.

[0069] The electrical insulating film 117 is formed of a silicon oxide (SiO_2) film, silicon nitride film, aluminum oxide film, polyimide film, or the like having a thickness of about 1 μm. The silicon oxide film is formed by sputtering, CVD, SOG (spin on glass), or the like. The silicon nitride film is formed by sputtering, CVD, or the like. The thickness of electrical insulating film 117 can be reduced to about 1 μm or less because sensor chip 103 is made of the stainless steel stock manufactured by special melting described above. More specifically, sensor chip 103 is made of a stainless steel stock fabricated by melting, with vacuum induction, a steel stock melted and cast by ordinary melting, and successively remelting it by a vacuum arc. The stainless steel stock manufactured by this special melting has high cleanness, and less particles and less pinholes than a general steel stock does, so that it can form an electrical insulating film uniformly.

[0070] Therefore, electrical insulating film 117 need not exceed a minimum thickness that can endure a dielectric breakdown voltage. In other words, particles and defects are very few, and the thickness of the electrical insulating film can be reduced. For example, electrical insulating film 117 may be formed thin within such a range that a breakdown voltage of about 100 V to 500 V and insulation of several 100 MΩ or more can be secured between sensor chip 103 and flow velocity detection mechanism 112 made of a conductor.

[0071] A printed board 105 disposed on sensor body 102 through a spacer 104 has a circular hole larger than diaphragm portion 128B at its center, and a plurality of wiring patterns 127 for forming a signal processing circuit are formed on its upper surface by printing. Electrode pads 114 of sensor chip 103 are electrically connected to wiring patterns 127 through bonding wires (not shown). The spacer 104 is made of stainless steel, aluminum, a synthetic resin, or the like in the same manner as sensor body 102 is. The spacer 104 is fixed to sensor body 102 with screws, an adhesive, or the like.

[0072] Fig. 11 shows the flow sensor according to the fifth embodiment , which is a so-called header type flow sensor. A header type flow sensor 130 is externally inserted and fitted in a sensor attaching hole 132 formed in the wall of a pipe 131 through which a fluid 107 flows, and is fixed by welding or the like. A sensor body 133, sensor chip 134, and attaching plate 135 forms a container, and a printed board 136 is accommodated in the container.

[0073] The sensor body 133 is made of stainless steel into a cylinder with two open ends, and its lower-surface opening which faces the interior of pipe 131 is closed with sensor chip 134 , which is formed of stainless steel into a thin plate with a thickness of about 50 μm to 150 μm. Its peripheral portion is bonded to the lower-surface opening of sensor body 133 by YAG laser welding or the like, and the bonded portion forms a diaphragm portion 134A. An electrical insulating film 117 is formed on that surface of diaphragm portion 134A which is on a side opposite to the surface to come into contact with fluid 107, in the same manner as in the flow sensor according to the fourth embodiment.

[0074] An indirect heated type flow velocity detection mechanism 112 including one heat-generating body (resistance heater) and two temperature sensors, electrode pads, thin metal films for wiring, and an ambient temperature detection mechanism 116 are formed on electrical insulating film 117.

[0075] As the material of sensor chip 134, a stainless steel stock fabricated by subjecting a stainless steel stock fabricated by ordinary melding and refining to ① double vacuum melting of vacuum induction melting (VIM) and subsequent vacuum arc remelting (VAR), or ② melting and casting by electroslab remelting (ESR), in the same manner as sensor chip 103 of the fourth embodiment is used. The ambient temperature detection mechanism 116 is arranged such that it can detect the fluid temperature without being adversely affected by heat from the heat-generating body.

[0076] Wiring patterns are formed on printed board 136, and flow velocity detection mechanism 112 and ambient temperature detection mechanism 116 arranged on ambient temperature detection mechanism 134 are connected to the wiring patterns through the thin metal films for wiring and electrode pads by wire bonding or the like. The wiring patterns are connected to lead pins 138 for external connection. The attaching plate 135 is integrally formed on the upper surface of sensor

body 133, and its peripheral portion is welded to the wall of pipe 131. Alternatively, attaching plate 135 may be attached with screws or the like by using an O-ring. The sensor body 133 and sensor chip 134 may be formed integrally.

[0077] In header type flow sensor 130 with the above structure, sensor chip 134 is also made of the stainless steel stock fabricated by remelting, with electroslab remelting, a steel lump melted and cast by ordinary melting. Therefore, sensor chip 134 has very few particles or defects, so that the thickness of electrical insulating film 117 can be reduced. Obviously, the same effects as those of the fourth embodiment described above can be obtained.

[0078] Operation and effects of the flow sensors according to the fourth and fifth embodiments will be described. In the flow sensor according to any one of the fourth and fifth embodiments, the thickness of the electrical insulating film can be sufficiently reduced with high yield, so that the sensitivity and response properties are improved.

[0079] Generally, in a sensor chip for a flow sensor, a temperature detection mechanism is fabricated on one surface of a substrate by photolithography and etching. As the material of the substrate, silicon, glass, or the like is usually used. If corrosion resistance and mechanical strength are required, a metal substrate made of stainless steel or the like is used. In this case, as the sensor chip is a conductor, an electrical insulating film is formed on it by an insulating film forming process, and after that a flow velocity detection mechanism made of a conductor is formed on the electrical insulating film. The fourth and fifth embodiments are particularly related to a thermal flow sensor which uses a stainless steel sensor chip.

[0080] To form a flow velocity detection mechanism on the surface of a stainless steel substrate through an electrical insulating film, usually, an electrical insulating film such as a silicon oxide film or silicon nitride film is formed by plasma CVD, and a flow velocity detection mechanism is fabricated on the electrical insulating film by photolithography and etching. A general-purpose stainless steel stock as the material of the substrate has many impurities (particles), e.g., Al_2O_3 or SiO_2, and defects (pinholes) in it and lacks cleanness. To fabricate a sensor having high yield and a high dielectric breakdown voltage, the electrical insulating film must be thick.

[0081] As described above, in the flow sensor in which the flow velocity detection mechanism is fabricated on the stainless steel sensor chip, the electrical insulating film is formed on the surface of the substrate by plasma CVD, and the flow velocity detection mechanism is fabricated on the electrical insulating film by photoetching. Generally, as an electrical insulating film has low thermal conductivity, it is preferably formed as thin as possible within such a range that it allows electrical insulation between the sensor chip and flow velocity detection mechanism. However, a sensor chip made of a general-purpose stainless steel stock (e.g., SUS304- or SUS316-based stainless steel) has many particles and defects. To improve insulation between the sensor chip and the flow velocity detector fabricated on it through an electrical insulating film, the electrical insulating film must be thick. In a thermal flow sensor, when the thickness of the electrical insulating film is increased, the heat transfer efficiency in the direction of thickness decreases, and the heat capacity increases. Hence, the sensitivity and response properties of the sensor cannot be improved.

A stainless steel stock fabricated by remelting and casting, in accordance with special melting, a steel lump melted and cast by ordinary melting is used as the material of the sensor chip. Thus, particles and defects from the sensor chip are few. An electrical insulating film which is to be formed on the upper surface of the sensor chip is made thin to a thickness of, e.g., about 1 μm or less. Then, the heat transfer efficiency of the sensor chip in the direction of thickness is improved, and the heat capacity can be reduced, so that the sensitivity and response properties of the sensor can be improved. A flow sensor suitably used particularly in a semiconductor manufacturing apparatus and ultrahigh-vacuum apparatus can be provided.

[0082] A flow sensor manufacturing method according to the sixth embodiment will be described.

[0083] The flow sensors described in the second to fifth embodiments can also be manufactured with the same manufacturing method.

[0084] Figs. 12A to 12G show a flow sensor manufacturing method according to the sixth embodiment of the present invention. Figs. 13A to 13C show a method of manufacturing the sensor chip portion of a flow sensor.

[0085] First, a stainless steel substrate material (substrate) (to be referred to as wafer hereinafter) 250 having a thickness of about 0.3 mm to 3 mm is prepared (Fig. 12A), and its surface 250a is mirror-polished (Fig. 12B).

[0086] Subsequently, a plurality of thin portions 250A, thick portions 250B, and recesses 250C are formed on the wafer 250 (Fig. 12C). Namely, a channel is formed by half etching, end milling, or the like. Each thin portion 250A and thick portion 250B form the diaphragm portion 124B and fixing portion 124A of substrate 124 described in the first embodiment. Each recess 250C forms the channel recess 106. The thin portions 250A are formed simultaneously when recesses 250C are formed in a lower surface 250b of wafer 250.

[0087] The recesses 250C are formed by photolithography and etching or end milling. When photolithography and etching are employed, first, a resist is applied to the entire lower surface 250b of wafer 250 by spin coating, and the resist-coated surface 250b is irradiated with ultraviolet radiation (or electron beams) to transfer and expose a mask pattern onto the resist. Then, the exposed resist is developed with a developing solution to remove the unnecessary portions of the resist. A neg-

ative resist or positive resist is chosen in accordance with whether the exposed portion is to be left or removed. The wafer 250 exposes from the resist-removed portion, and the exposing wafer portion is removed by wet etching or dry etching until the thickness of thin portions 250A is about 50 μm to 150 μm.

[0088] Subsequently, the remaining resist is separated and removed, and the wafer is cleaned. Thus, fabrication of thin portions 250A and channel recesses 250C is completed. In the case of wet etching, the wafer is dipped in an etching solution, or an etching solution is sprayed to the wafer, so the resist is dissolved. In the case of dry etching, the lower surface of wafer 250 is irradiated with ions or electrons by sputtering or a plasma, so the resist is removed little by little.

[0089] Subsequently, an electrical insulating film 213 formed of a silicon oxide film, silicon nitride film, or a multilayered film comprised of them is formed on the entire upper surface of wafer 250 (Fig. 12D). When insulating film 213 is a silicon oxide film, it is formed by sputtering, CVD, SOG (spin on glass), or the like , and when it is a silicon nitride film, it is formed by sputtering, CVD, or the like.

[0090] Subsequently, a flow velocity detection mechanism 212 is fabricated, by known thin film forming technique, on that portion of insulating film 213 which covers each thin portion 250A, and electrode pads 114, thin metal films 115 for wiring, and an ambient temperature detection mechanism 216 are fabricated around it by the known thin film forming technique (Fig. 12E). Namely, a flow sensor is formed. For example, the flow sensor is fabricated by depositing a metal such as platinum having a large temperature coefficient of resistance on the upper surface of electrical insulating film 213 and performing photolithography and etching described above.

[0091] Subsequently, the wafer 250 is cut and separated into the individual flow velocity detection mechanisms 212 by etching, dicing, or the like, to fabricate a plurality of sensor chips 251 simultaneously (Fig. 12F). That is, the sensors are separated by etching and wire cutting or dicing. When cutting wafer 250, it may be cut at the centers of adjacent thick portions. With this cutting, wafer 250 forms the substrates 124 each shown in Fig. 1. When the plurality of sensor chips 251 is simultaneously fabricated from one wafer 250 in this manner, sensor chips having a substantially constant quality can be manufactured on the mass production basis, so that the manufacturing cost can be reduced.

[0092] Subsequently, sensor chip 251 and a channel forming member 202 having two channel holes 209 and 210 are stacked, and are welded by laser welding (Fig. 12G). The substrate 124 shown in Fig. 1 corresponds to substrate 206 shown in Fig. 12G. After this, a printed wiring board 105 identical to that shown in Fig. 1 is stacked on channel forming member 202 through a spacer 104, and wiring patterns 127 of the printed wiring board 105 and electrode pads 114 are electrically connected to each other, to complete flow sensor 100 shown in Figs. 1 and 2.

[0093] Figs. 13A to 13C show part of a manufacturing procedure employing the method according to the seventh embodiment.

[0094] This manufacturing method is different from the manufacturing method of the sixth embodiment only in that the wafer is fabricated by stacking two substrate materials. Except for this, the steps of the seventh embodiment are the same as those of the sixth embodiment.

[0095] First, a thin, first stainless steel substrate material 260 with a thickness of about 50 μm to 150 μm and having a mirror-finished upper surface is fabricated (Fig. 13A). A second plate-like stainless steel substrate material 262 with a thickness of about 0.3 mm to 3 mm and having a plurality of channel holes 261 is formed (Fig. 13B). The channel holes 261 are formed by etching, end milling, or the like, and are used each as channel recess 106 of the flow sensor shown in Fig. 1.

[0096] Subsequently, first and second substrate materials 260 and 262 are bonded by diffusion bonding or the like to fabricate a wafer 263 having a multilayered structure. Of the first substrate material 260, portions 264 corresponding to channel holes 261 of the second substrate material 262 each form the thin diaphragm portion 124B of substrate 124 of flow sensor 100 shown in Fig. 1.

[0097] With diffusion bonding, the bonding surfaces of bonding members to be bonded are brought into tight contact with each other and heated and pressurized in a vacuum, so they are bonded to each other by utilizing diffusion of atoms generated between the bonding surfaces. Accordingly, no bonding material is needed, and high corrosion resistance can be obtained. Also, with diffusion bonding, variations in thickness of the diaphragm portion of the sensor chip can be minimized. To obtain reliable bonding, the bonding members are preferably heated at an appropriate temperature (about 900°C to 1,300°C). In this case, as the first and second substrate materials 260 and 262 are fabricated from stainless steel, no stress is generated by a difference in thermal expansion coefficient.

[0098] The manufacturing procedure from Fig. 13C is the same as that of Figs. 12D to 12G, and description thereof will accordingly be omitted.

[0099] Figs. 14A to 14C show some steps in a method of manufacturing a flow sensor according to the eighth embodiment.

[0100] The substrate 124 of flow sensor 100 shown in Fig. 1 is made of sapphire, and channel forming member 102 is made of stainless steel.

[0101] First, a sapphire wafer 270 with a thickness of about 0.3 mm to 3 mm and having a mirror-polished surface 270a is prepared (Fig. 14A).

[0102] Subsequently, a plurality of recesses 270C are formed in a lower surface 270b of the wafer 270 by a laser, end milling, etching, ultrasonic machining, or the like, to form thin portions 270A and thick portions 270B

(Fig. 14B). That is, a flow channel is formed. Each thin portion 270A has a thickness of about 50 μm to 150 μm.

[0103] A flow velocity detection mechanism 212 is arranged on the upper surface of each thin portion 270A of wafer 270, and electrode pads 114, thin metal films 115 for wiring, and an ambient temperature detection mechanism 216 are arranged around it. These components are fabricated by the known thin film forming technique in the same manner as in the method of the sixth embodiment described with reference to Fig. 12E, and accordingly will not be shown or described. In this case, as the sapphire wafer 270 is an insulating material, the electrical insulating film 213 described above need not be formed on the upper surface of wafer 270 in advance. In this respect, fabrication of wafer 270 is different from that of stainless substrate 124.

[0104] Subsequently, wafer 270 on which flow velocity detection mechanisms 212, electrode pads 114, thin metal films 115 for wiring, and ambient temperature detection mechanisms 216 are fabricated is cut and separated by etching, dicing, laser machining, or the like along the center lines of thick portions 270B, to fabricate a plurality of sensor chips 271 (Fig. 14C). Each chip 271 and a channel forming member 202 having two channel holes 209 and 210 are stacked and bonded to each other (Fig. 14C). When bonding, the lower surface of sensor chip 271 is metallized with a metal film of molybdenum, tungsten, or the like in advance, and sensor chip 271 is bonded to the channel forming member 202 by brazing. After that, a printed board 105 identical to that shown in Fig. 1 is disposed above the upper surface of the sensor chip 271 through a spacer 104, and wiring patterns 127 of printed board 105 and electrode pads 114 are electrically connected to each other, thus completing a sapphire flow sensor.

[0105] Figs. 15A to 15C show steps in a method of manufacturing a flow sensor by diffusion bonding, wherein, first, a first thin sapphire substrate material 274 with a thickness of about 50 μm to 150 μm and having a mirror-finished upper surface is fabricated in the same manner as with the manufacturing method shown in Figs. 13A to 13C (Fig. 15A). A second plate-like sapphire substrate material 276 with a thickness of about 0.3 mm to 3 mm and having a plurality of channel holes 275 is fabricated (Fig. 15B). The channel holes 275 are formed by laser machining, etching, end milling, ultrasonic machining, or the like, and are used each as channel recess 106 of flow sensor shown in Fig. 1.

[0106] Subsequently, first and second substrate materials 274 and 276 are bonded by diffusion bonding or the like to prepare a wafer 277 having a multilayered structure (Fig. 15C). Of first substrate material 274, portions corresponding to channel holes 275 of second substrate material 276 each form diaphragm portion 124B of the flow sensor 100 shown in Fig. 1.

[0107] According to this manufacturing method, since the first and second substrate materials 274 and 276 are made of sapphire, no stress is caused by a difference in thermal expansion coefficient. With diffusion bonding, the bonding surfaces of bonding members to be bonded are brought into tight contact with each other and are heated and pressurized in a vacuum, so they are bonded to each other by utilizing diffusion of atoms generated between the bonding surfaces. Accordingly, no bonding material is needed, and high corrosion resistance can be obtained.

[0108] Figs. 16A to 16D show steps in a method of manufacturing according to the 10th embodiment, wherein the substrate 124 of flow sensor 100 shown in Fig. 1 and channel forming member 102 are both made of a ceramic material.

[0109] First, a calcining mold 280 for a wafer is prepared (Fig. 16A). A ceramic powder or temporarily molded ceramic member 281 is charged in the calcining mold 280. The calcining mold 280 is then loaded in a calcining furnace 282 and heated and calcined at a predetermined temperature for a predetermined period of time (Fig. 16B), to prepare a ceramic wafer 283. Namely, a wafer with a channel is fabricated by ceramic calcining. The wafer 283 has a thickness of about 0.3 mm to 3 mm, and a plurality of thin portions 283A, thick portions 283B, and recesses 283C. The thickness of each thin portion 283A is about 50 μm to 150 μm. Alternatively, a ceramic member 281 formed by pressing without using the calcining mold 280 may be directly calcined in the calcining furnace 282 to prepare the wafer 283.

[0110] Subsequently, the surface of wafer 283 is mirror-polished. After that, a flow velocity detection mechanism 212 is arranged on each thin portion 283A, and electrode pads 114, thin metal films 115 for wiring, and an ambient temperature detection mechanism 216 are arranged around it. These components are fabricated by exactly the same method as described with reference to Fig. 12E, and accordingly will not be shown or described. In this case, as the sapphire wafer 283 is an insulating material in the same manner as the sapphire wafer described above, no electrical insulating film 213 need be formed on it in advance.

[0111] Subsequently, wafer 283 on which flow velocity detection mechanisms 212, electrode pads 114, thin metal films 115 for wiring, and ambient temperature detection mechanisms 216 are fabricated is cut and separated by dicing or the like along the center lines of thick portions 283B, to fabricate a plurality of sensor chips 284 (Fig. 16D). Each sensor chip 284 and a channel forming member 202 having two channel holes 209 and 210 are bonded to each other by brazing or the like after their portions to be stacked to each other are metallized with molybdenum, tungsten, or the like. The channel forming member 202 is made of a ceramic material. Hence, a wafer is fabricated by heating and calcining in the same manner as, e.g., wafer 283, and thereafter is cut and separated by dicing or the like, thus forming channel forming member 202. Alternatively, channel forming member 202 may be fabricated by ordinary machining.

[0112] After that, a printed board 105 identical to that of the flow sensor shown in Fig. 1 is disposed above the upper surface of sensor chip 284 through a spacer 104, and wiring patterns 127 of printed board 105 and electrode pads 114 are electrically connected to each other, thus completing a ceramic flow sensor.

[0113] In any one of the flow sensor manufacturing methods described in the sixth to 10th embodiments, when the substrate material is either one of stainless steel, sapphire, and a ceramic material, the plurality of sensor chips 251, 271, or 284 with a uniform quality can be fabricated simultaneously by cutting and separating a single wafer into small pieces. Thus, mass production with a batch process is possible to reduce the manufacturing cost.

[0114] The present invention is not limited at all to the embodiments described above, but can be changed and modified. For example, the materials of substrate 124 and channel forming member 202 can be changed when necessary. The substrate 124 and channel forming member 202 may be bonded to each other with bolts or the like through a seal member such as an O-ring, or may be adhered to each other through an adhesive or the like. The channel holes 209 and 210 formed in channel forming member 202 are not limited to through holes extending through the upper and lower surfaces of member 202, but may be L-shaped holes extending through the upper and side surfaces of member 202. The surface of the substrate material may be mirror-polished after recesses 106 are formed, and the shapes of recesses 106 are not limited to ellipses. The manufacture of the sensor chips is not limited to mass production in accordance with the batch process, but the sensor chips may be fabricated one by one.

[0115] Operation and effects of the flow sensor manufacturing methods shown in the sixth to 10th embodiments will be described.

[0116] Conventionally, a flow sensor of this type is used mainly for a noncorrosive gas, and recently a sensor which can also be used for a liquid or corrosive gas has been developed. For example, a mass flow sensor disclosed in Japanese Patent Laid-Open No. 7-159215 is known. According to this mass flow sensor, a silicon substrate is bonded to a glass substrate which forms a channel where a fluid flows, to come into contact with the channel. A flow rate detection heater is arranged on that surface of the silicon substrate which is on a side opposite to the channel. In this mass flow sensor, as the heater does not come into direct contact with the fluid, degradation of the heater caused by the fluid can be prevented, and good detection characteristics can be maintained after a long term use.

[0117] In the conventional mass flow sensor, however, the channel for the measurement target fluid is fabricated with a silicon substrate and a glass substrate. When the mass flow sensor is to be used in a semiconductor manufacturing apparatus or the like, it cannot because the silicon substrate and glass substrate may be corroded by a corrosive gas or liquid. The silicon substrate has high thermal conductivity. When the temperature of the entire substrate becomes uniform due to heat of the heater, a temperature difference is not easily caused between the upstream and downstream heaters by the flow of the fluid, and the detection sensitivity is accordingly low. In addition, the silicon substrate is formed to be smaller than the glass substrate in order to reduce the heat capacity, and projects above the glass substrate, thus forming a step between the two substrates. This degrades handling and manufacture in the later manufacturing process. For example, regarding the manufacturing facilitation, the silicon substrate is made to be smaller than the glass substrate by removing its unnecessary portions other than a portion that covers the channel of the silicon substrate, by photolithography and etching. Thus, two steps of photolithography and etching are added.

[0118] In the flow sensor manufacturing method according to any one of the sixth to 10th embodiments, a plurality of sensor chips can be manufactured on a mass production basis by a batch process, so that the manufacture can be facilitated while the manufacturing cost can be reduced. According to this manufacturing method, chips made from a single body can be originally fabricated by the batch process. Particularly, with the batch process, a plurality of sensor chips with a uniform quality can be manufactured on the mass production basis. Thus, productivity can be improved and the manufacturing cost can be reduced.

[0119] As the substrate and the channel forming member are fabricated from stainless steel, sapphire, or a ceramic material, a flow sensor having high heat resistance and high corrosion resistance can be fabricated, and measurement of a liquid or corrosive gas can be coped with. Particularly, stainless steel is very suitable in terms of corrosion resistance, workability, thermal conductivity, and rigidity. If the corrosion resistance must be particularly high, sapphire is suitable. As the flow velocity detection mechanism does not come into direct contact with the fluid, a sensor having high reliability and high durability can be provided.

[0120] With the flow sensor according to the invention, since a change in flow velocity or flow rate characteristics of a sensor chip caused by the pressure change of the fluid is small, measurement precision, reproducibility, reliability, and durability of the sensor can be improved, and the sensor can be fabricated with a smaller number of components.

[0121] With the flow sensor according to the invention, a stainless steel stock prepared by remelting and casting, in accordance with special melting, a steel lump melted and cast by ordinary melting is used as the material of the sensor chip. Thus, particles and defects from the sensor chip are few. An electrical insulating film which is to be formed on the upper surface of the sensor chip can be made thin to a thickness of, e.g., about 1 μm or less. Hence, the heat transfer efficiency of the

sensor chip in the direction of thickness is improved, and the heat capacity can be reduced, so that the sensitivity and response properties of the sensor can be improved. A flow sensor suitably used particularly in a semiconductor manufacturing apparatus and ultrahigh-vacuum apparatus can be provided.

[0122] With the flow sensor manufacturing method according to the invention, chips made from a single body can be originally fabricated by the batch process. Particularly, with the batch process, a plurality of sensor chips with uniform quality can be manufactured on the mass production basis. Thus, productivity can be improved and manufacturing costs can be reduced. As the substrate and the channel forming member are fabricated from stainless steel, sapphire, or a ceramic material, a flow sensor having high heat resistance and high corrosion resistance can be fabricated, and measurement of a liquid or corrosive gas can be coped with. Particularly, stainless steel is very suitable in terms of corrosion resistance, workability, thermal conductivity, and rigidity. If the corrosion resistance must be particularly high, sapphire is suitable.

[0123] As the flow velocity detection mechanism does not come into direct contact with the fluid, a sensor having high reliability and high durability can be provided.

Claims

1. A flow sensor **characterized by** comprising:

    a substrate (124, 156, 128) in which a diaphragm portion (124B, 156B1, 128B) having a first surface in contact with a measurement target fluid (107, 102) and a thick fixing portion (124A, 156A, 128A) surrounding the diaphragm portion are integrally formed;
    an electrical insulating film (113, 117) formed on a second surface of the diaphragm portion which is on a side opposite to the first surface; and
    flow velocity detecting means (112, 125) arranged on the electrical insulating film (113, 117).

2. A sensor according to claim 1, further comprising a channel forming member (102) which forms a channel (108) for the measurement target fluid (107) together with the substrate (124, 128).

3. A sensor according to claim 2, wherein the channel forming member (102) and the substrate (124, 128) are integrally formed.

4. A sensor according to claim 1, wherein
    the substrate (156) is disposed to cover a sensor attaching hole (152) formed in a pipe (151) through which the measurement target fluid (102) flows, and
    the flow velocity detecting means (125) is arranged on the second surface of the diaphragm portion (156B1).

5. A sensor according to claim 1, wherein
    the substrate (124) is made of any one material selected from the group consisting of stainless steel, sapphire, and a ceramic material.

6. A sensor according to claim 1, wherein
    the substrate (128) is made of a stainless steel stock prepared from a steel lump fabricated by melting and casting, and
    the second surface of the diaphragm portion (128B) is polished.

7. A sensor according to claim 6, wherein the stainless steel stock is fabricated by melting and casting the steel lump with vacuum induction melding and thereafter melting and casting a resultant material with vacuum arc remelting.

8. A sensor according to claim 6, wherein the stainless steel stock is fabricated by melting and casting the steel lump by electroslab remelting.

9. A sensor according to claim 1, wherein the flow velocity detecting means (112, 125) comprises
    a heat-generating body (120) and
    two temperature sensors (121A, 121B).

10. A sensor according to claim 1, wherein the electrical insulating film (113, 117) is made of any one material selected from the group consisting of silicon oxide, silicon nitride, alumina, and polyimide.

11. A sensor according to claim 2, further comprising
    a spacer (104) arranged on the channel forming member (102), and
    a printed wiring board (105) arranged above the substrate (124) through the spacer (104).

12. A sensor according to claim 1, further comprising
    an electrode pad (114) arranged on the electrical insulating film (113, 117), and
    a thin metal film (115) for wiring for connecting the electrode pad and the flow velocity detecting means (112, 125) to each other.

13. A sensor according to claim 1, further comprising
    ambient temperature detecting means (116, 113) arranged on the second surface of the diaphragm portion,
    an electrode pad (114) formed on the electrical insulating film (113, 117), and
    a thin metal film (115) for wiring for connecting the electrode pad and the ambient temperature de-

tecting means to each other.

14. A flow sensor manufacturing method including the steps of:

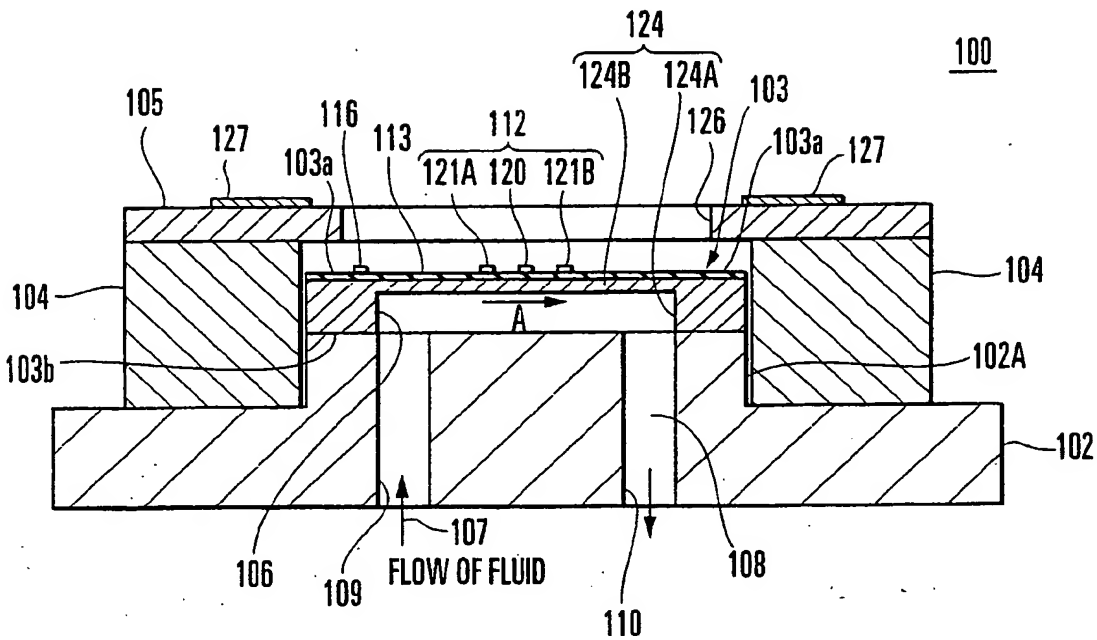
forming a sensor chip (251) having a substrate (124) and flow velocity detecting means (212), the substrate (124) having at least one channel recess (250C) at a central portion of a lower surface thereof, a thin portion (250A) at the central portion forming a diaphragm portion (124B), and the flow velocity detecting means being formed on an upper surface of the diaphragm portion;
bonding a channel forming member (202) to a lower surface of the sensor chip (251); and
forming a fluid for a measurement target fluid with the channel forming member and the channel recess of the substrate, **characterized in that**
the step of forming the sensor chip (251) comprises the steps of
forming a channel recess in a lower surface (250b) of a substrate (250) to leave a thin portion on an upper surface thereof, thus forming at least one diaphragm portion in the thin portion, and
forming flow velocity detecting means at a portion of the upper surface of the substrate which corresponds to the diaphragm portion.

15. A method according to claim 14, wherein
said method further comprises the step of forming a plurality of sensor chips by separating the substrate to correspond to respective channel detecting means, and
the step of forming the diaphragm portion comprises the step of forming a plurality of channel recesses in the lower surface of the substrate (250) to leave thin portions on the upper surface thereof.

16. A method according to claim 14, wherein the step of forming the diaphragm portion comprises the steps of
fabricating a first thin substrate,
fabricating a second plate-like substrate having a channel hole, and
stacking and diffusion-bonding the first and second substrates.

17. A method according to claim 14, wherein the substrate is made of stainless steel, and an electrical insulating film is formed on the upper surface of the substrate.

18. A method according to claim 14, wherein the substrate is made of any one material selected from the group consisting of sapphire and a ceramic material.


124
124B
124A
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105
127
116
113
112
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121B
126
103
103a
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102
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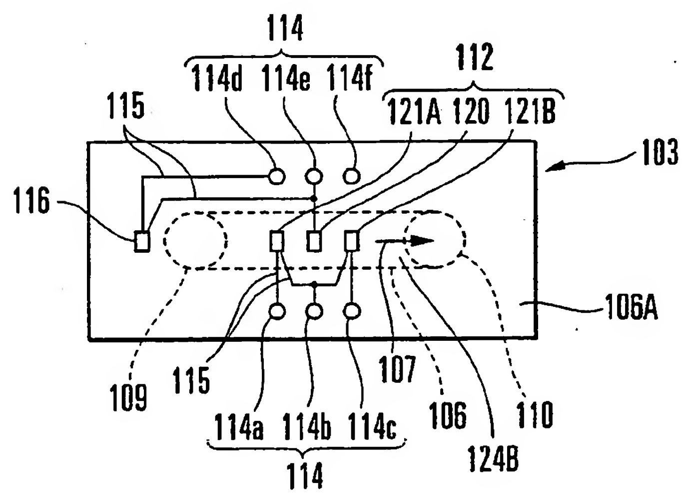
109
107
FLOW OF FLUID
110
108

FIG. 1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114d
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114f
112
121A
120
121B
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103
116
106A
109
115
107
106
110
114a
114b
114c
124B
114

FIG. 2

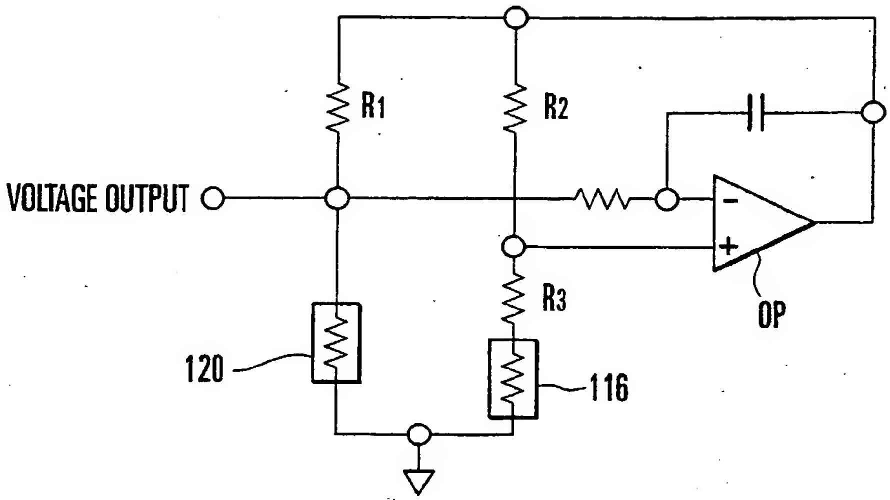

R1
R2
VOLTAGE OUTPUT
-
+
R3
OP
120
116

FIG. 3

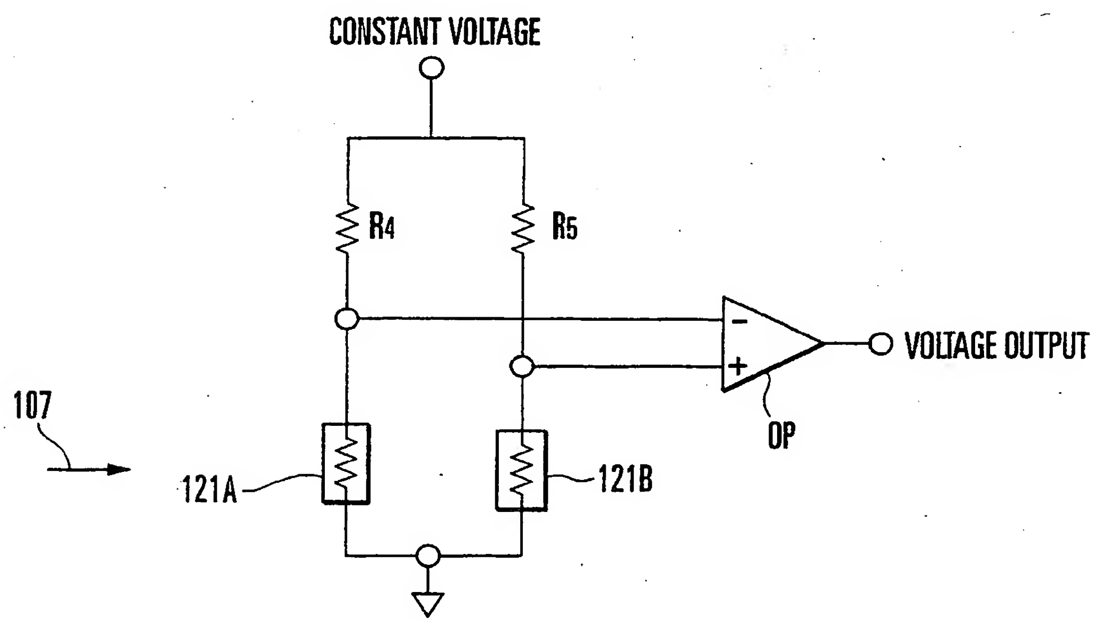

CONSTANT VOLTAGE
R4
R5
-
+
VOLTAGE OUTPUT
OP
107
121A
121B

FIG. 4

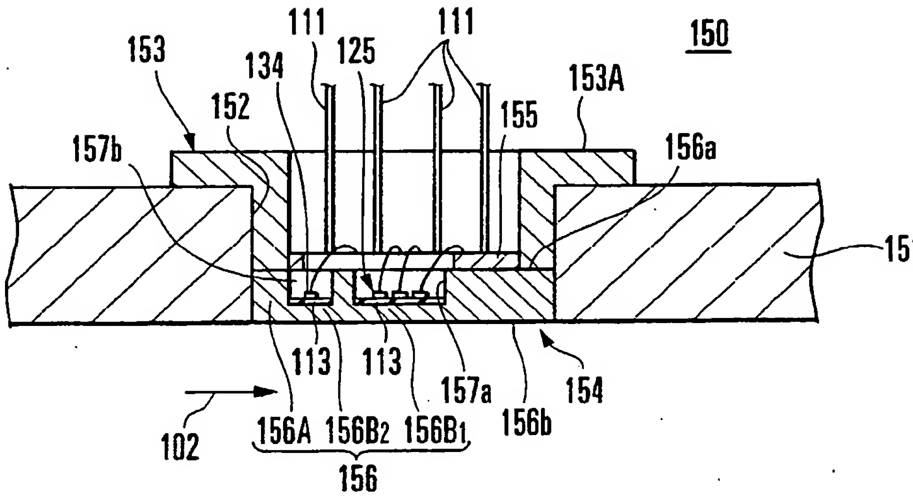


FIG. 5

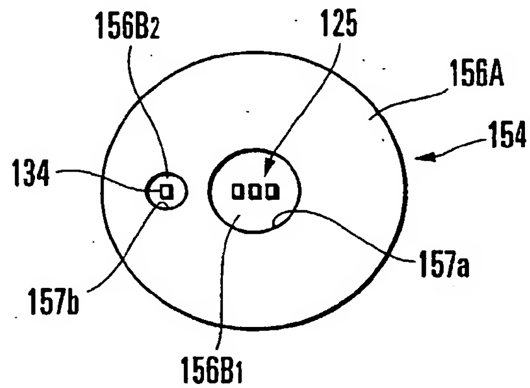


FIG. 6

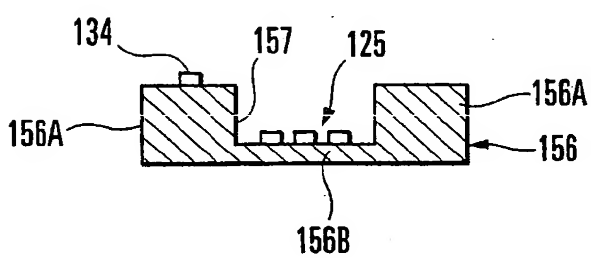


FIG. 7

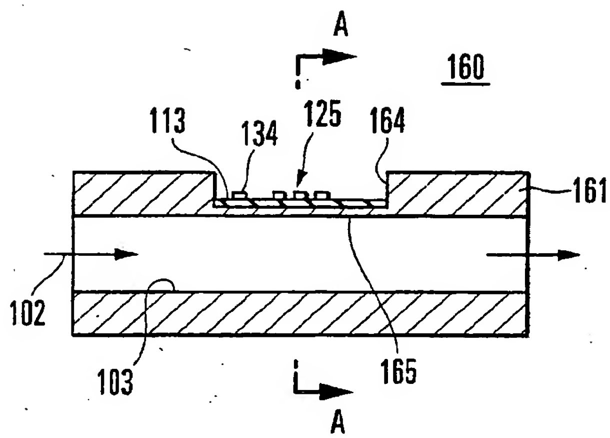


FIG.8A

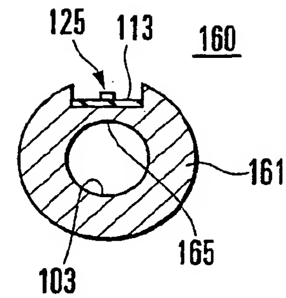


FIG.8B

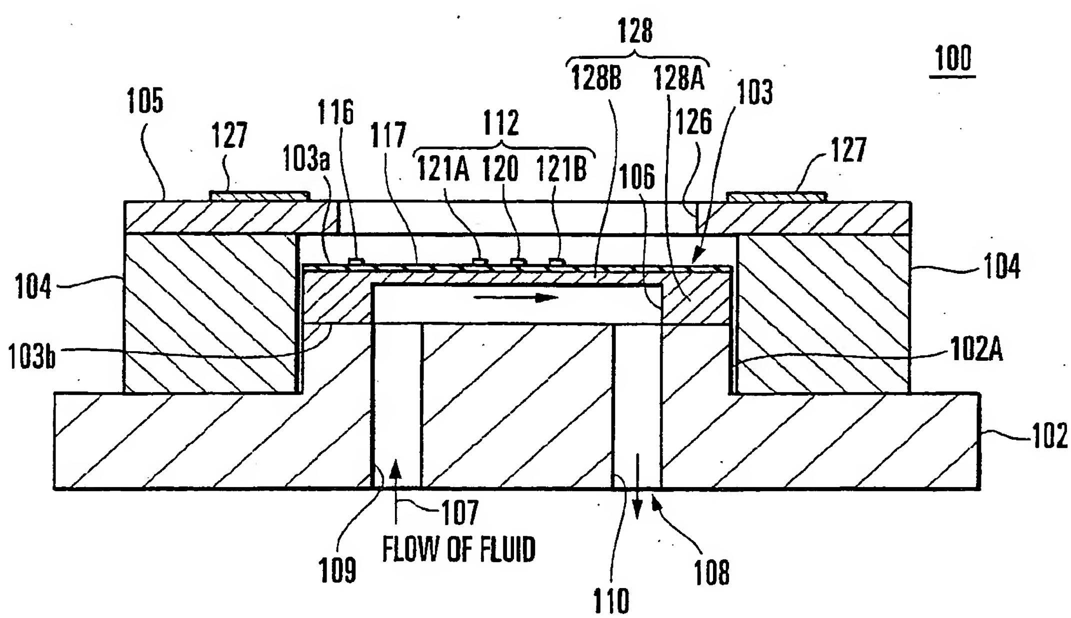


FIG.9

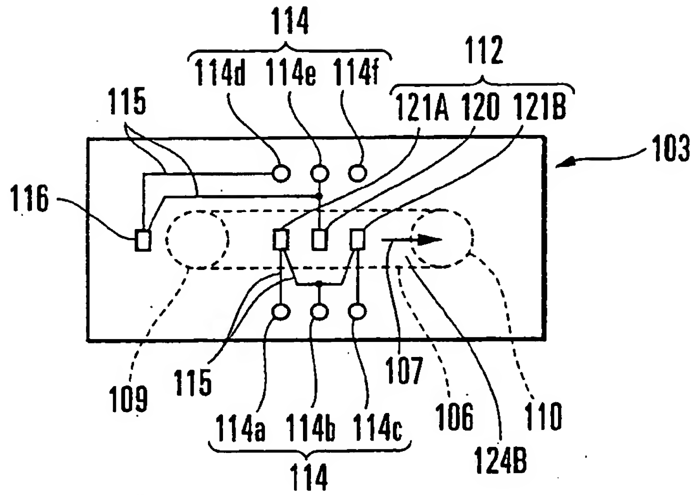

114
114d 114e 114f
112
121A 120 121B
115
103
116
115
107
109
114a 114b 114c
106
110
124B
114

FIG. 10

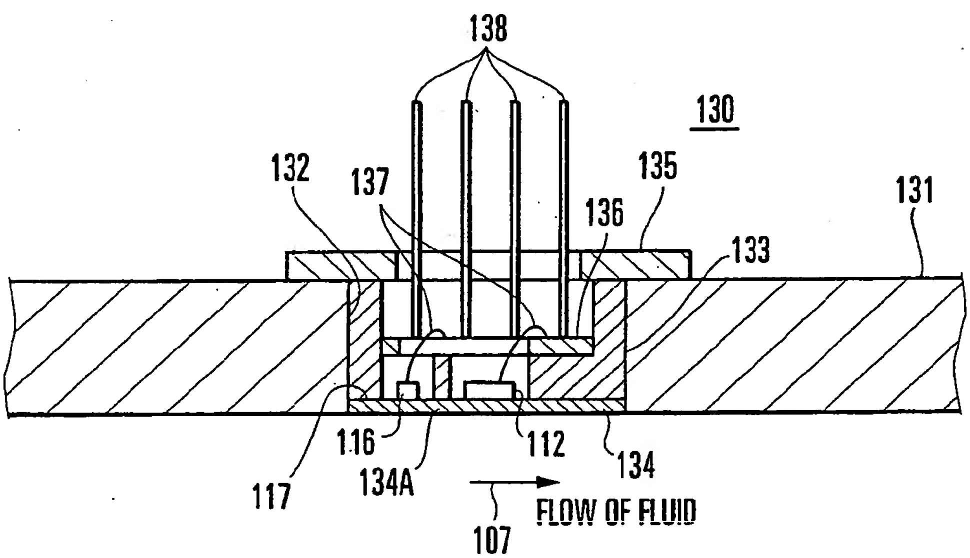

138
130
132
137
135
136
131
133
116
112
134
117
134A
107
FLOW OF FLUID

FIG. 11

FIG.12A

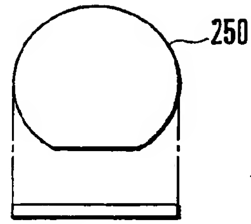


FIG.12B

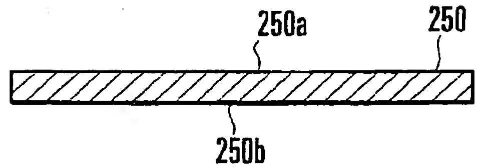


FIG.12C

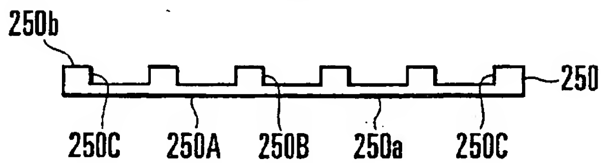


FIG.12D

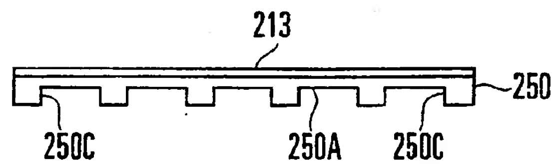


FIG.12E

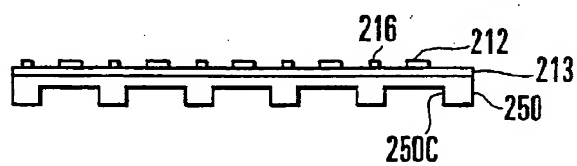


FIG.12F

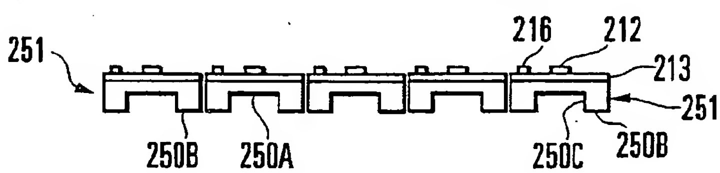


FIG.12G

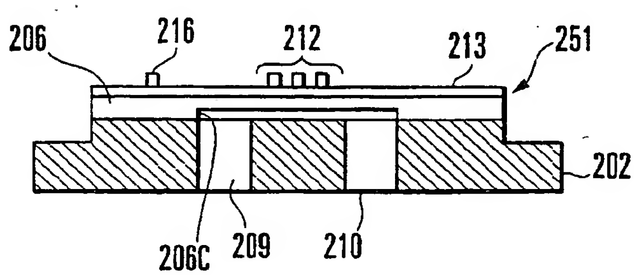


FIG.13A

FIG.13B

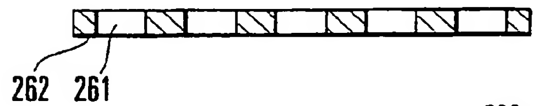


FIG.13C

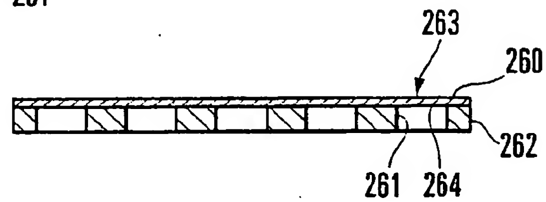


FIG.14A

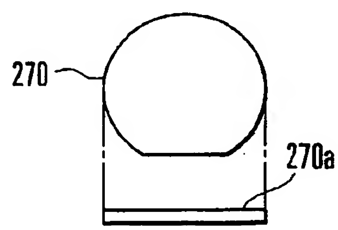
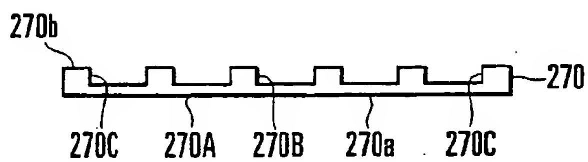


FIG.14B



THE SAME AS FIGS. 12E AND 12F
AND ACCORDINGLY NOT SHOWN

FIG.14C

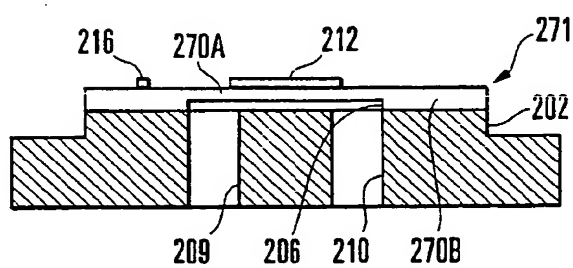


FIG.15A

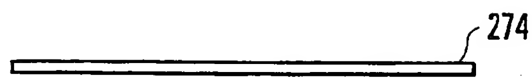


FIG.15B

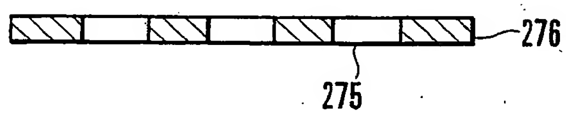


FIG.15C

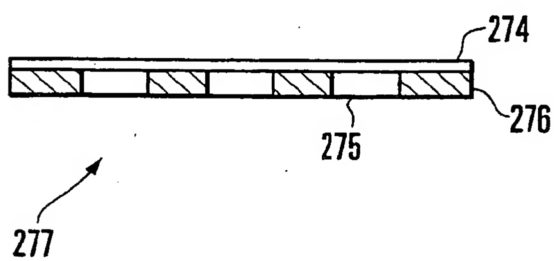


FIG.16A

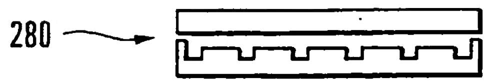


FIG.16B

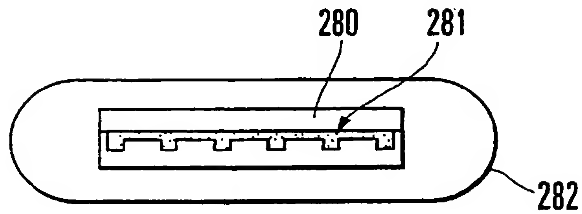
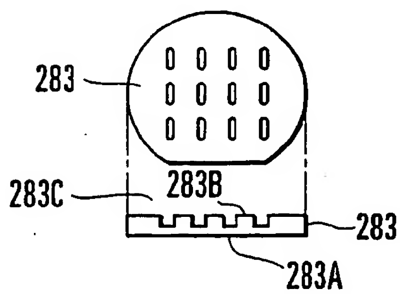
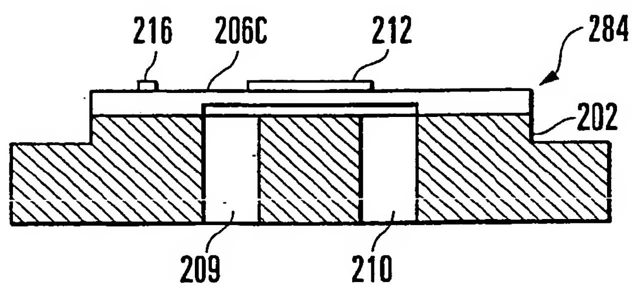


FIG.16C



THE SAME AS FIGS. 12E AND 12F
AND ACCORDINGLY NOT SHOWN

FIG.16D



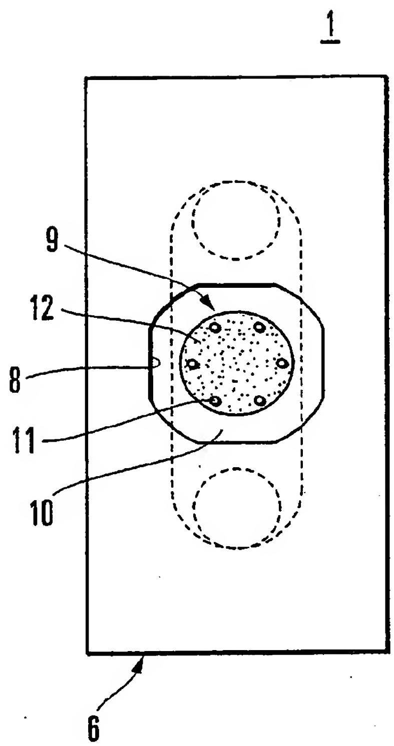


FIG.17A
PRIOR ART

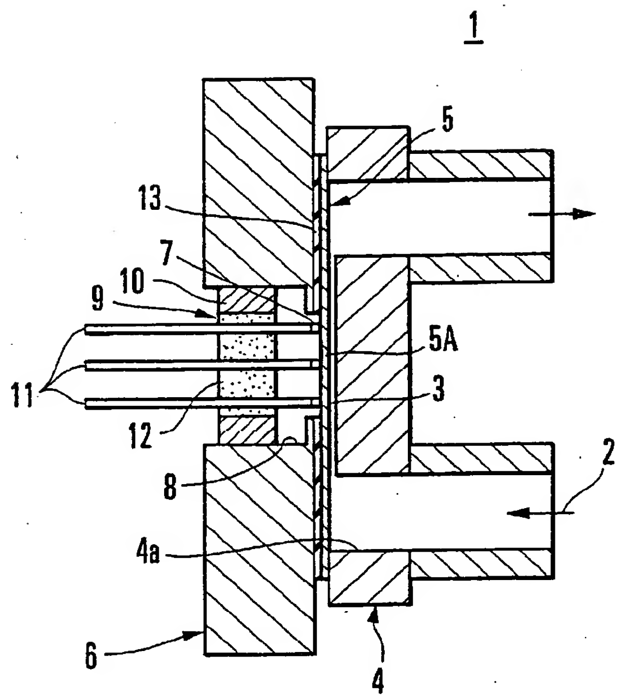


FIG.17B
PRIOR ART

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 09 0136

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
Y	HIRATA K ET AL: "Stainless steel-based integrated mass-flow controller for reactive and corrosive gases" SENSORS AND ACTUATORS A, ELSEVIER SEQUOIA S.A., LAUSANNE, CH, vol. 97-98, 1 April 2002 (2002-04-01), pages 33-38, XP004361579 ISSN: 0924-4247 * the whole document *	1-18	G01F1/684 G01F1/68 G01F1/692
Y	WO 02 33362 A (YAMATAKE CORP; IKE SHINICHI (JP); KAMIUNTEN SHOJI (JP); TANAKA HID) 25 April 2002 (2002-04-25) * abstract; figures 1A,1B,1C *	1-18	
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	25 September 2003	Politsch, E

CATEGORY OF CITED DOCUMENTS

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T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
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L : document cited for other reasons

& : member of the same patent family, corresponding document

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